

Anvil Turbulence as measured by the WB-57
during CRYSTAL-FACE

Leonhard Pfister, NASA/Ames

Paul Bui, NASA/Ames

Jon Dean Day, San Jose State University

contact: lpfister@mail.arc.nasa.gov

Synopsis

Small scale motions in cumulus anvils are important because of their potential ability to transport heat, momentum, moisture, and ice. Also, the speed with which the turbulence decays may have an impact on the lifetime of ice particles. Finally, the strength of the small scale motions is an indication of how high the resolution of anvil models must be. This poster is a PRELIMINARY study of anvil turbulence during the CRYSTAL-FACE mission, performed using the PRELIMINARY 20 hz data from the Meteorological Measurement System on the WB-57. Our approach is to examine the vertical velocity and vertical heat fluxes from anvil passes at 13-15 km on two flights during CRYSTAL-FACE, compare these to data from convective systems during CAMEX measured a few kilometers lower, and try to understand similarities and differences.

On July 16, the WB-57 investigated an isolated anvil system that formed around 19Z. Convection was fairly brief, and the anvil detached and moved westward rapidly in the strong upper level flow. The aircraft managed 6 passes through the anvil, the first four of which are displayed in Fig 1 (a-d). Figure 2 shows, on top, time series of vertical velocity and SPP-100 Ice Water Content. Note maximum vertical velocities are about 3 meters per second in both directions. The bottom part of Figure 2 is a wavelet analysis, showing the amplitude of vertical velocity as a function of time (horizontal axis) and horizontal scale (vertical axis). The idea is to see not only how the magnitude of vertical velocity varies, but at what wavelengths it is enhanced. There is clearly enhancement at small scales (10 km or less) associated with each anvil pass, even for the later ones where the vertical velocity amplitude itself is weak. Notably, the decay is rapid, with maximum power down by 1-2 decades in the 2 hours between passes 2 and 6.

Figure 3 shows comparisons of vertical velocity spectra for four convective passes, two from CAMEX (where the DC-8 passed through convective updrafts at 10 km over the Keys), the second and most turbulent pass on July 16 (Pass 2), and the famous “lightning strike” pass on July 7. Other than overall power (about a decade higher during the powerful updraft phase during CAMEX than during the anvil pass on July 16), we note a systematically steeper falloff in the 1-10 Hz range for the CRYSTAL passes (close to a -3 power law) as opposed to CAMEX (close

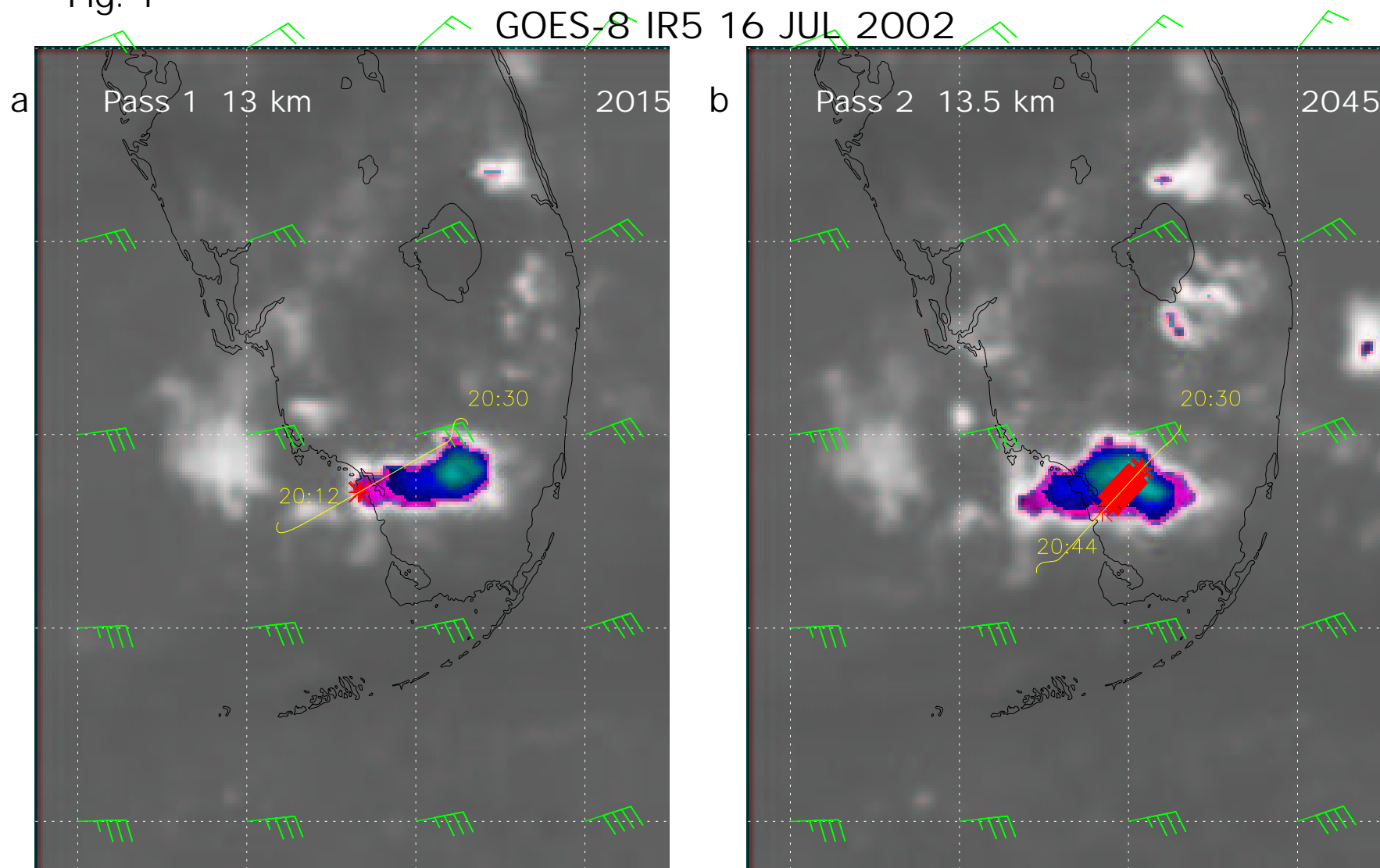
to $-5/3$). We will try to offer some explanation of this difference by examining the properties of the vertical heat flux and the anvil environment.

Figure 4 shows the vertical heat flux for the first four July 16 anvil passes, and the distribution of that heat flux as a function of horizontal scale. Most of the flux occurs at scales between 5 and 50 km, on the long scale side of the spectral peak in vertical velocity (Figure 3). Notably, the heat flux is mostly negative for pass 2 with the highest vertical velocity power. Figure 5 shows the “lightning strike” pass on July 7, with the vertical velocity power distribution (as in Figure 2) on the left, and the heat flux distribution (as in Figure 4) on the right. Scales of the heat flux are comparable to (though a little smaller than) those for July 16. Again, the heat flux is negative. Figure 6 shows vertical velocity power distribution and heat flux distribution for the CAMEX cases. The “developing” and “mature” phases for which Figure 3 power spectra were calculated are labeled. Reflecting the less steep vertical velocity falloff, heat flux is concentrated at smaller scales than in the CRYSTAL cases. Also, we see a positive heat flux in the developing case (warm air rising, cold air sinking), consistent with active convection.

A reason for the negative heat flux for the “lightning strike” pass can be seen in Figure 7, which shows a vertical profile through the pass. The enhanced vertical velocity occurs just at the top of the near-adiabatic layer below 13.6 km, above which ozone and potential temperature jump. The turbulence (excited by the convection) is chewing at the bottom of the stratosphere and bringing high ozone and high potential temperature air into the anvil (downward heat flux). The stable layer on top of the anvil is probably squishing the vertical velocity as well, leading to something more like 2-D turbulence (-3 power law) rather than 3-D ($-5/3$ power law). The July 16 case is more subtle. Figure 8 shows Passes 2 and 3 in a vertical profile. Pass 2 is at the highest altitude the aircraft reaches during the anvil passes, but it is not at the tropopause (about 14.8 km). However, a region of enhanced stability at Pass 2 (accompanied by jumps in ozone) is clearly apparent. The convection has reached its top, creating an inversion above it and is chewing on that inversion. That same inversion is squishing the turbulence and making it more two-dimensional.

Fig. 1

GOES-8 IR5 16 JUL 2002



NMC 200 mb windbarbs

SSP100 IWC >.04

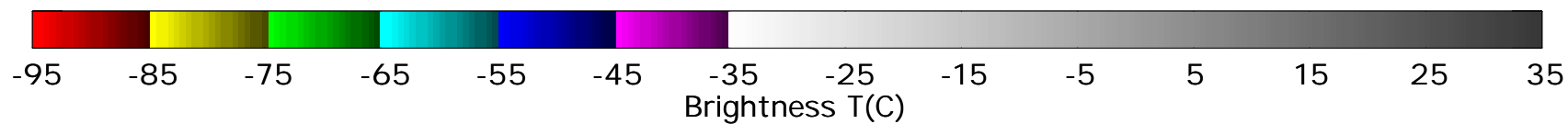
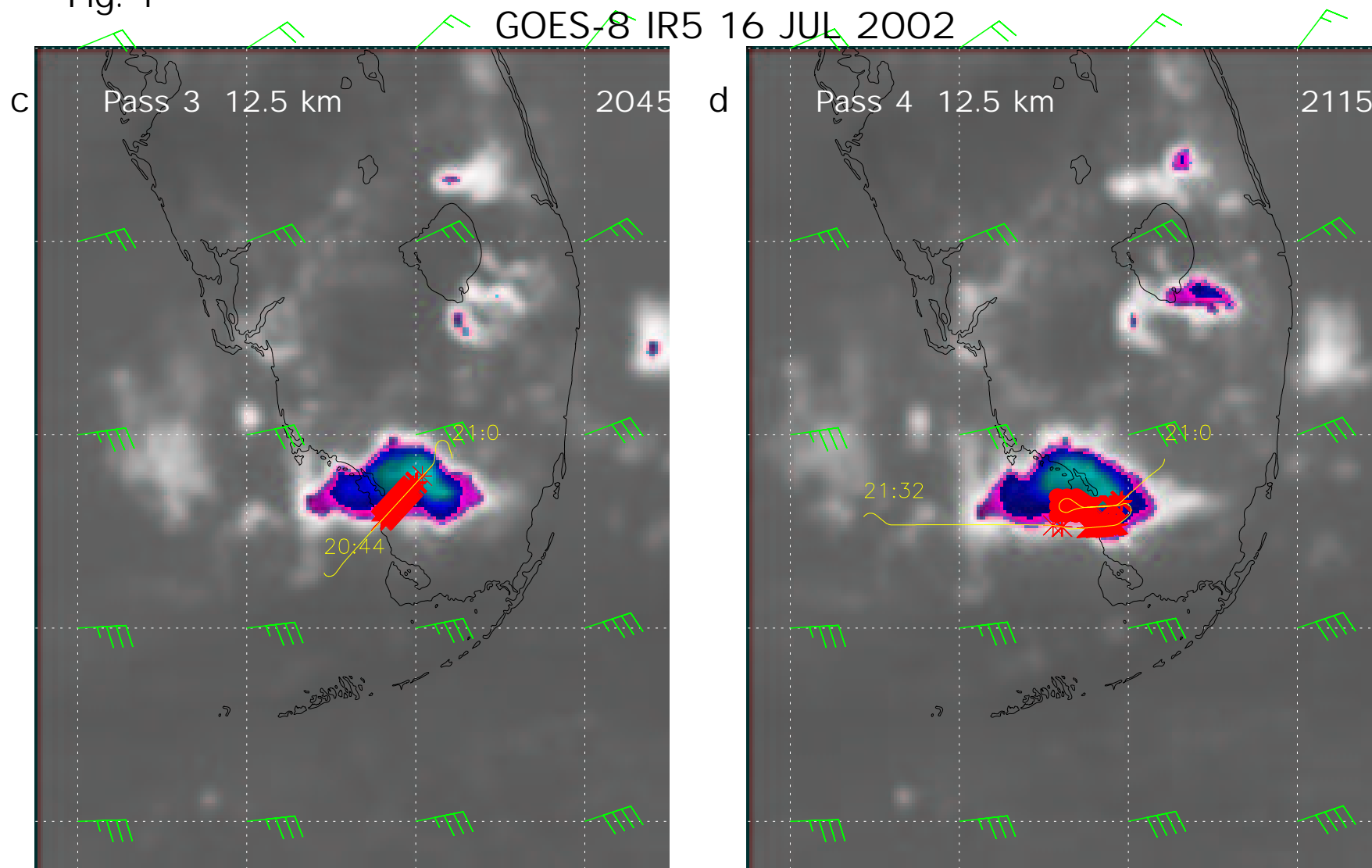


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GOES-8 IR5 16 JUL 2002



NMC 200 mb windbarbs

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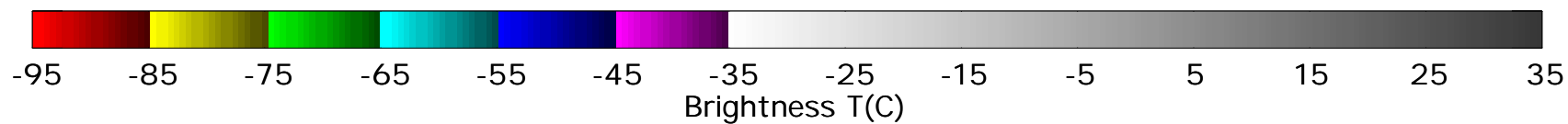
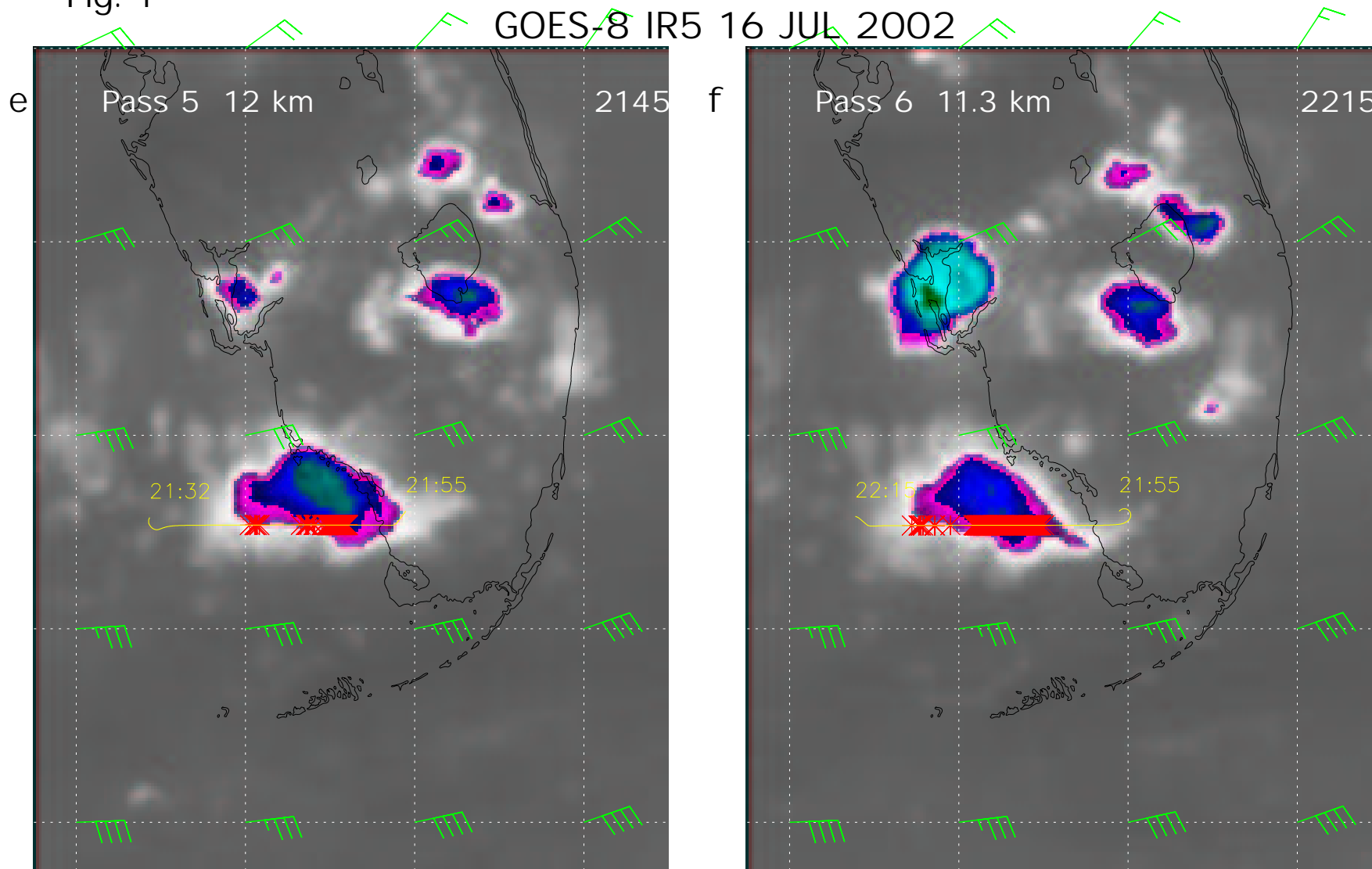


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GOES-8 IR5 16 JUL 2002



NMC 200 mb windbarbs

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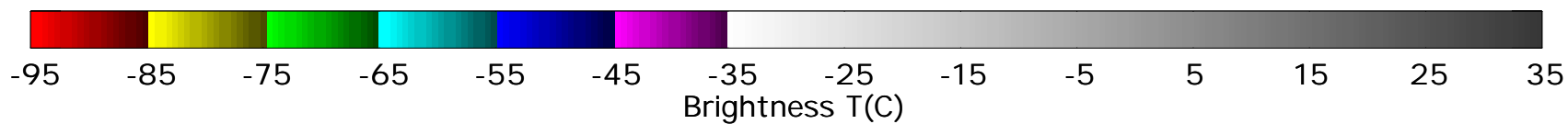


Fig 2: Vertical Velocity and Ice Water Content from 20020716

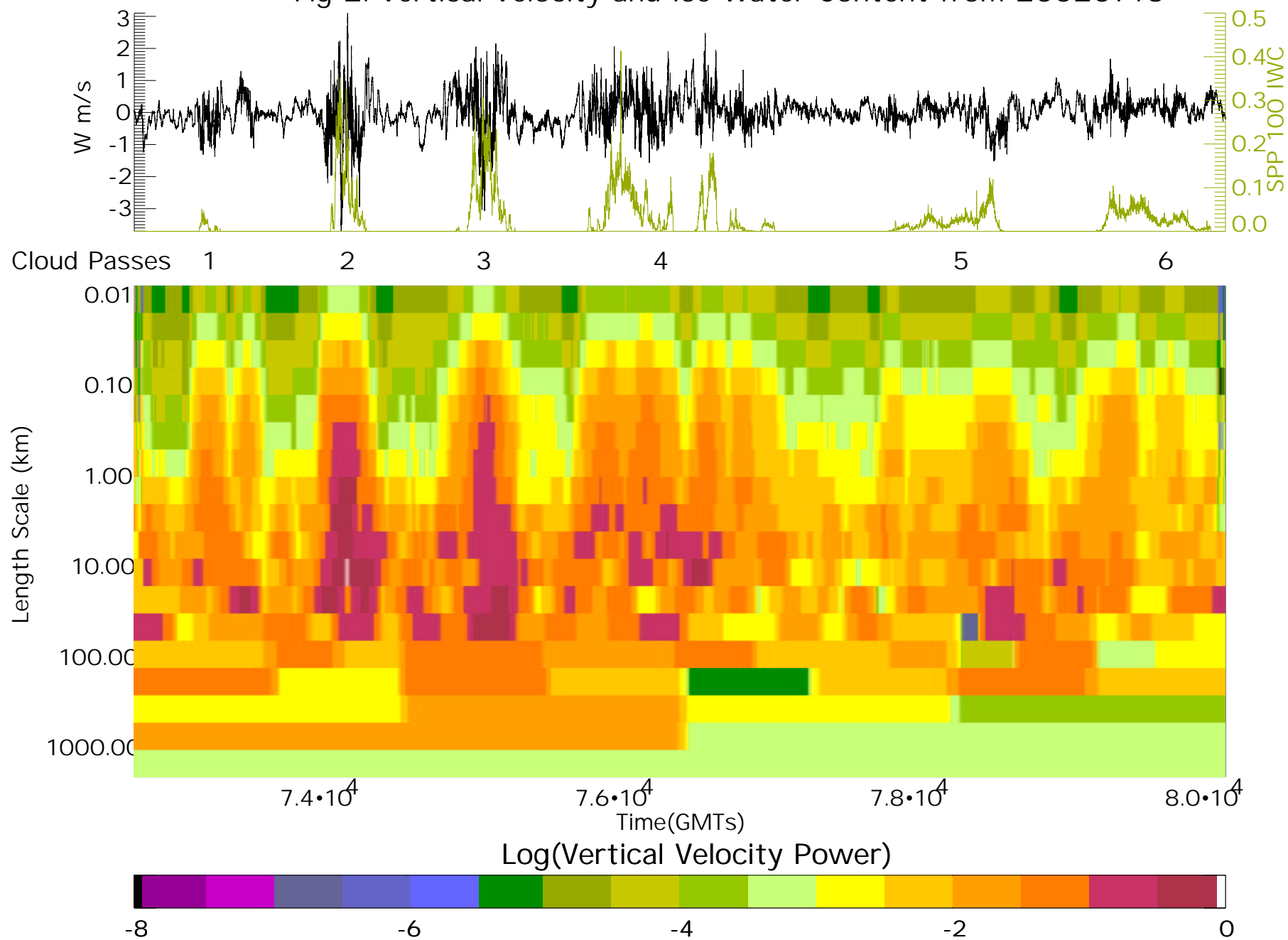


Fig 3: Vertical Velocity Power Spectra

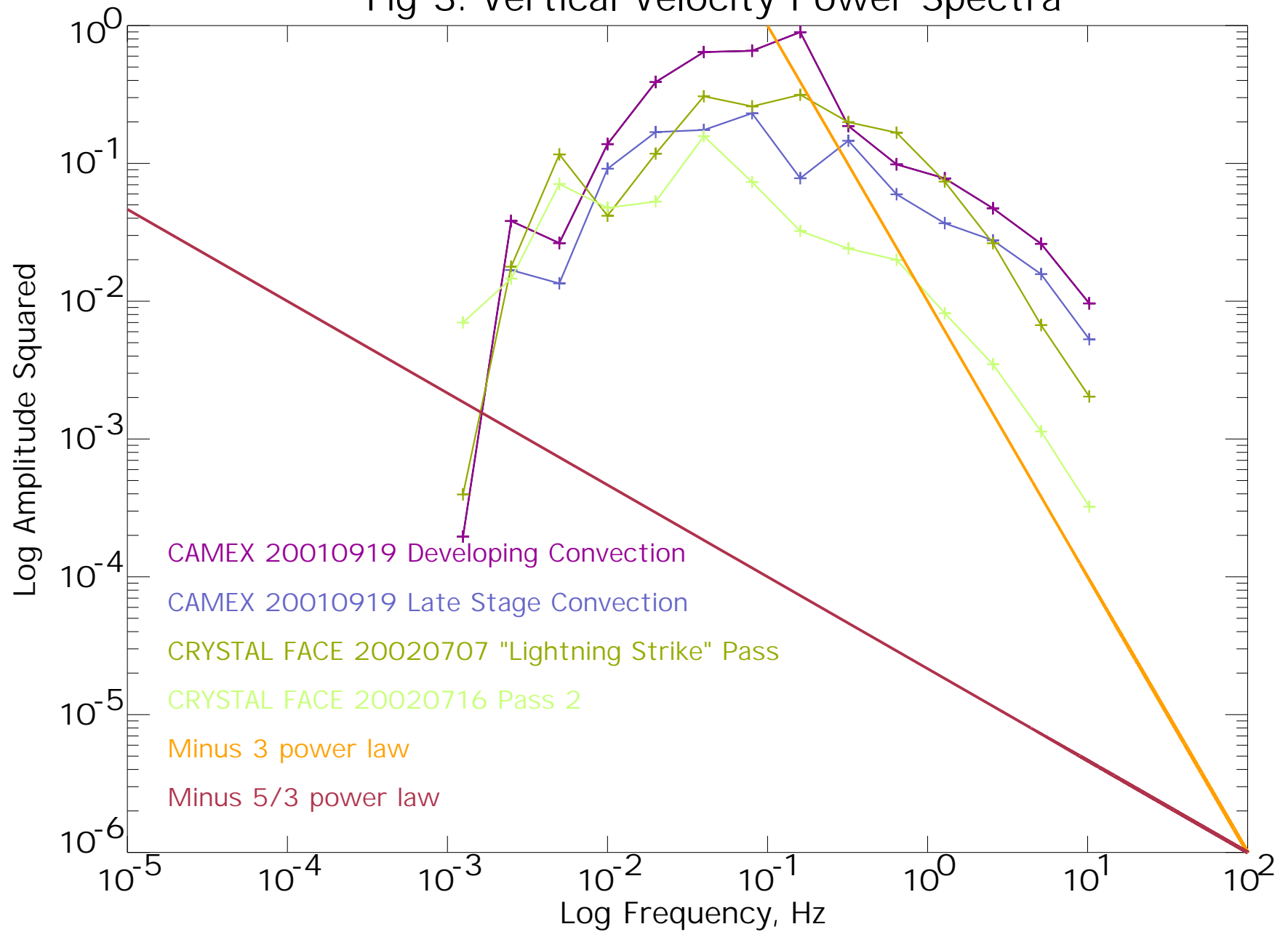


Fig 4: 20020716 Vertical Theta Flux

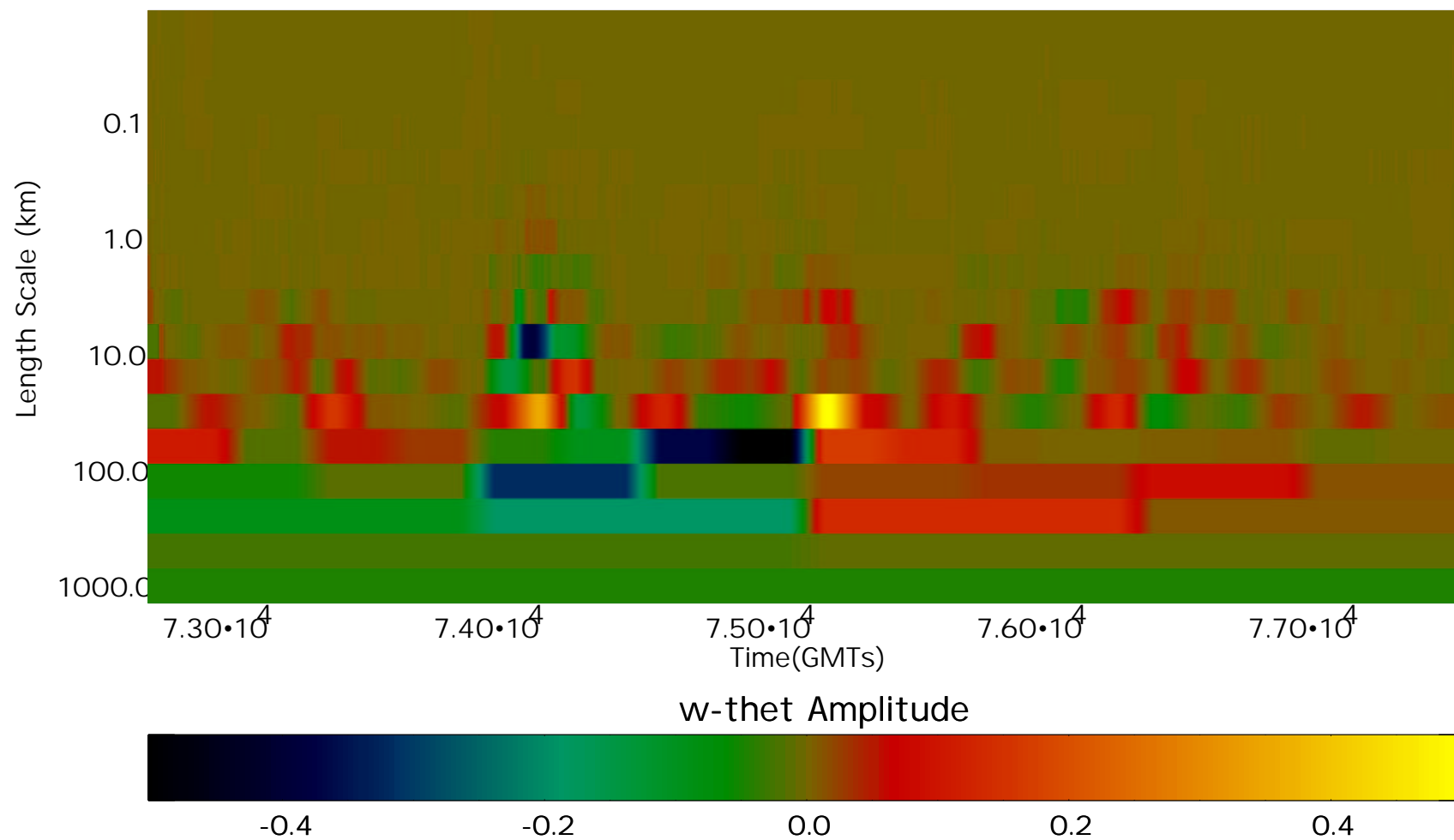
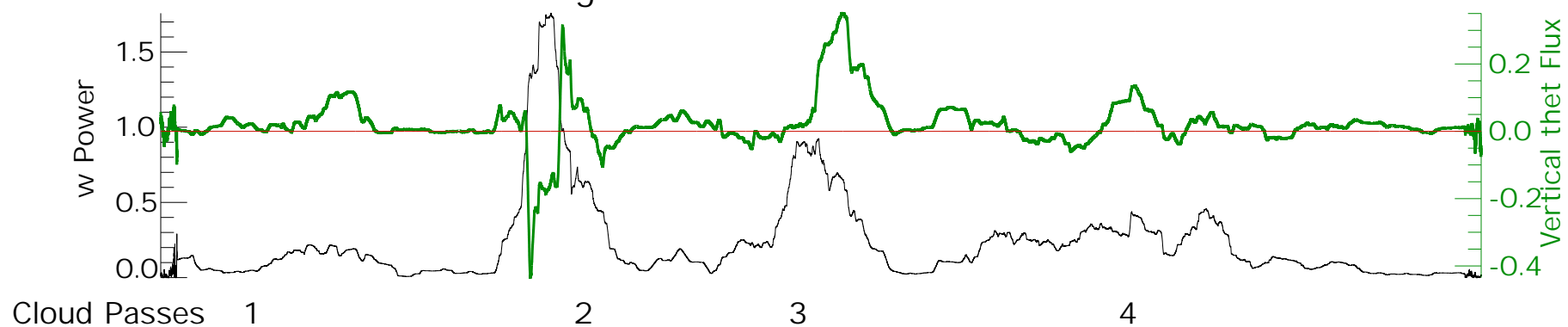


Figure 5: 20020707 "Lightning Strike" Pass

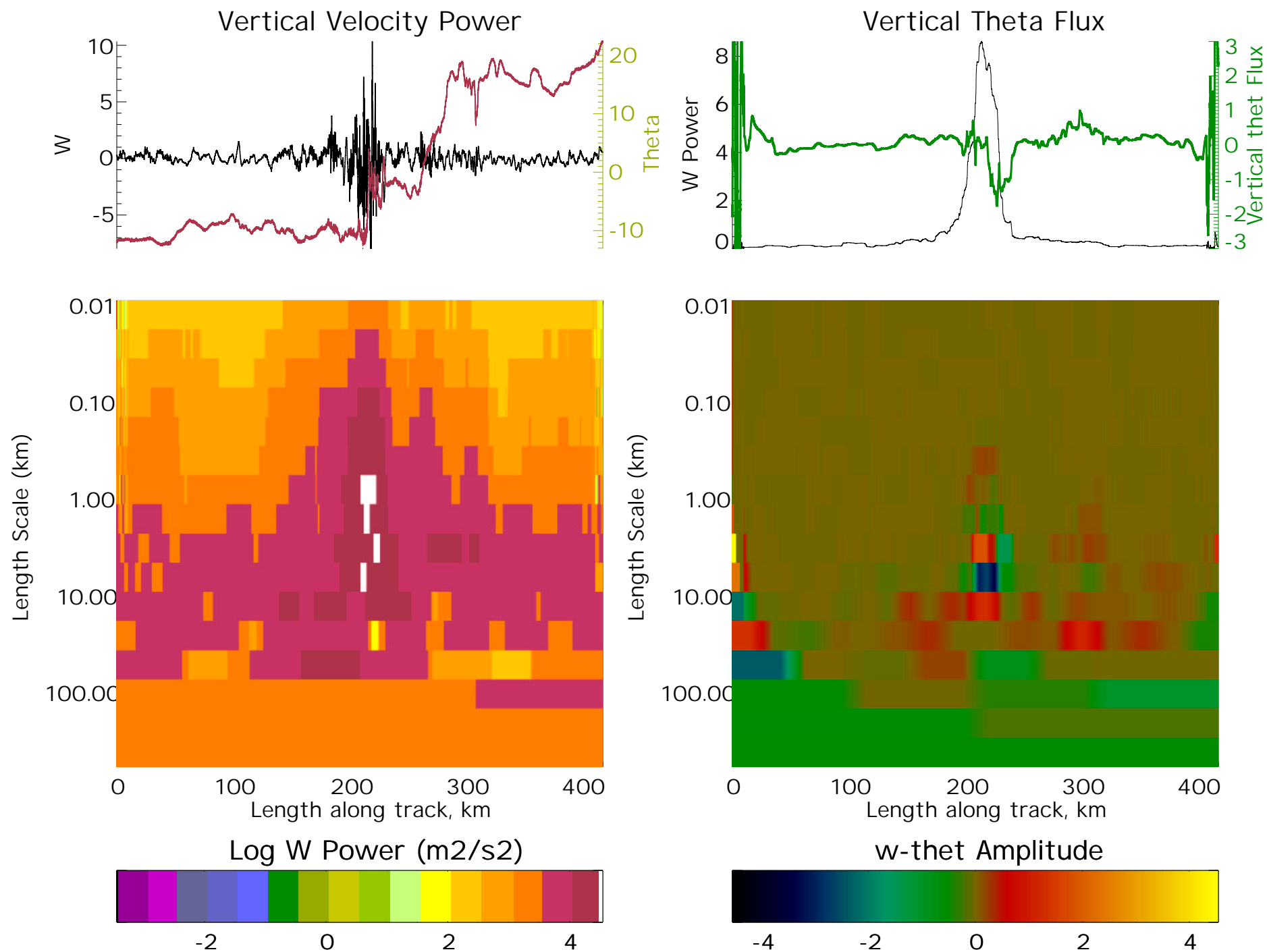
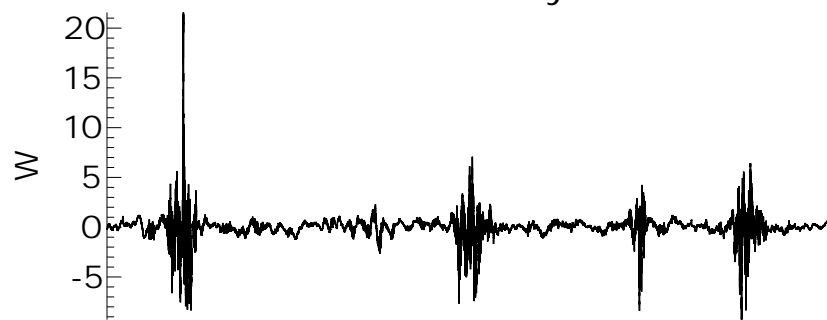
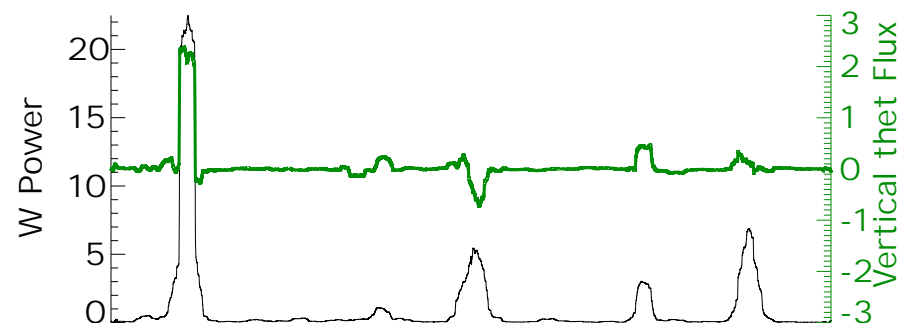


Figure 6: 20010919 CAMEX Convection at 10.1km

Vertical Velocity Power

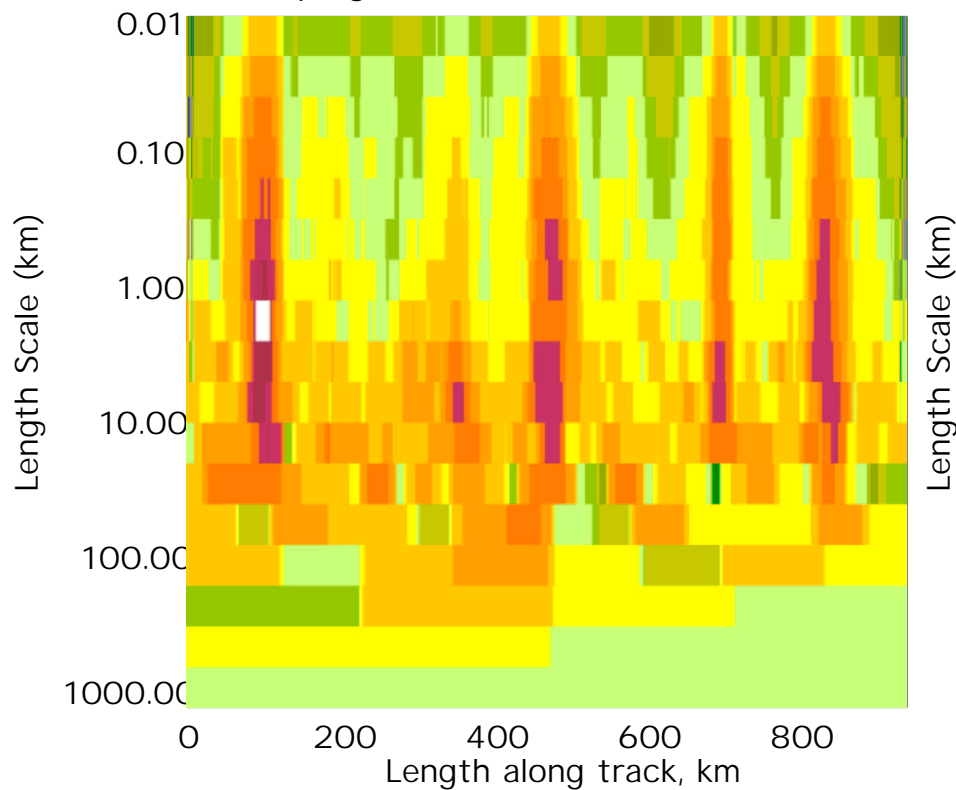


Vertical Theta Flux

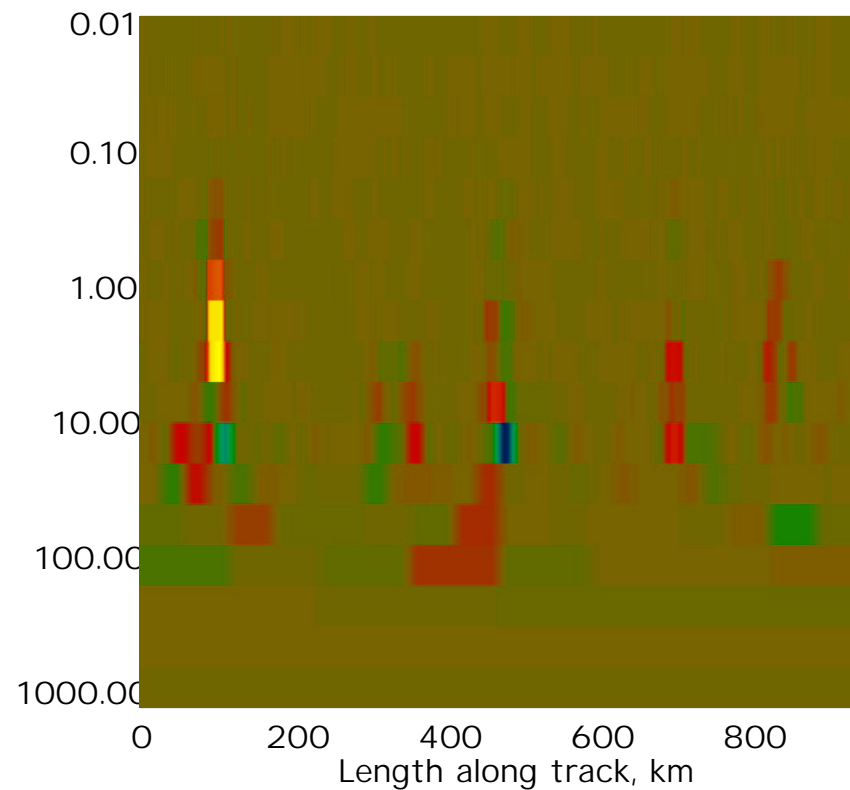
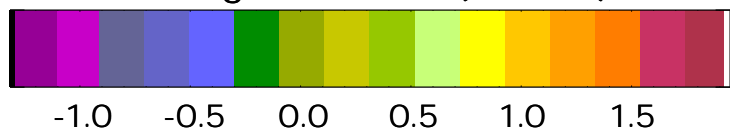


Passes Developing

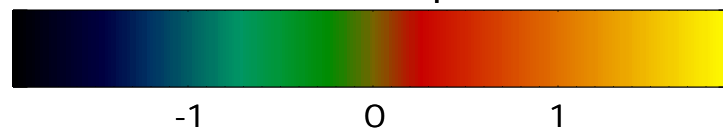
Mature



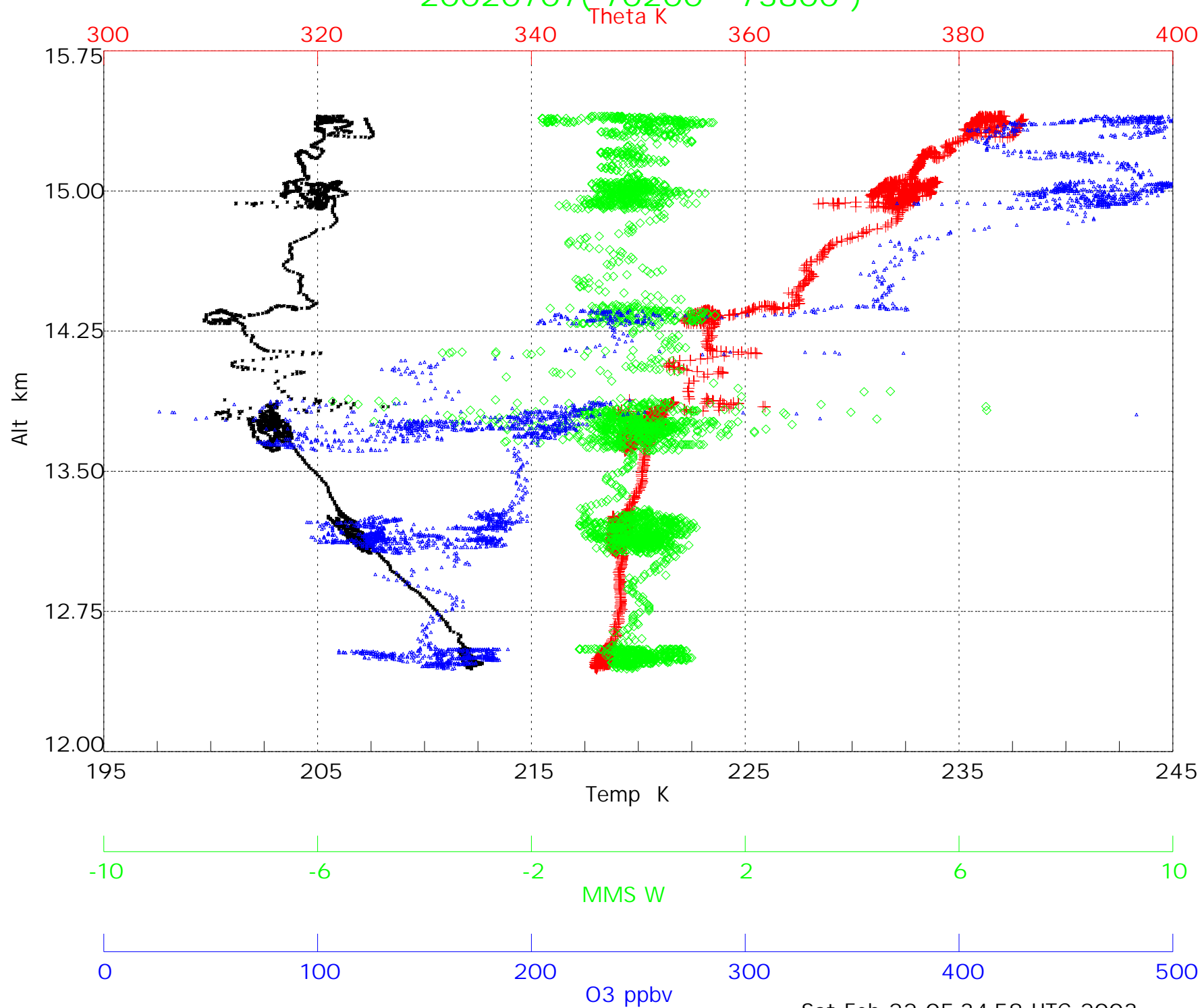
Log W Power (m2/s2)



w-thet Amplitude

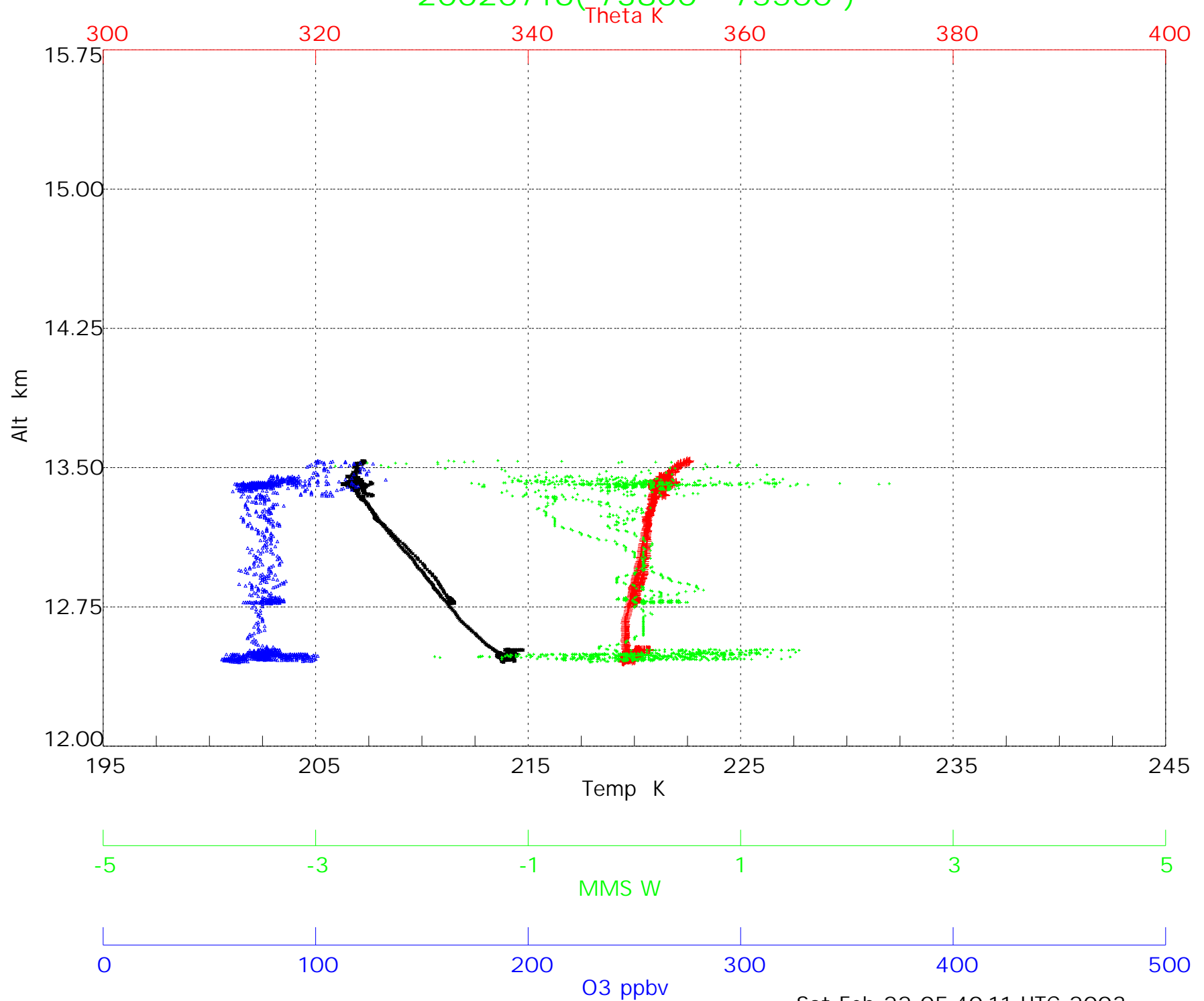


20020707(70200 - 73800)



Sat Feb 22 05:34:58 UTC 2003

20020716(73800 - 75500)



Sat Feb 22 05:40:11 UTC 2003

Conclusions

We have examined vertical velocity variations and heat fluxes during two CRYSTAL-FACE WB-57 anvil flights near the tropopause and compared them with convection observed during CAMEX at lower altitudes in the upper troposphere. Some conclusions follow:

- There is a clear enhancement in small scale vertical velocity during anvil passes that decays rapidly as the anvil ages (Figures 1 and 2).
- The spectral falloff at small scales (1-10hz) is very steep during the anvil passes (about -3), much steeper than during the upper tropospheric convection (about -5/3) (Figure 3).
- Heat fluxes during the anvil passes with the strongest vertical velocities are negative, contrasting with significant positive heat fluxes in upper tropospheric CAMEX convection (Figures 4 through 6).
- The negative heat fluxes in the anvils and spectral falloff are consistent with the high stabilities found just above the anvils, which allow turbulence to transport high potential temperature air downward into the anvil. The high stability, in turn, would tend to suppress the three-dimensional character of the turbulence (Figures 7 and 8).